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Stress concentration around countersunk hole in composite plate

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ABSTRACT

The application of composite plates is increasing in modern applications like in aerospace, underwater transportation and other industrial applications because of their high strength to weight ratio, high strength, high stiffness, low density and long fatigue life. Proper knowledge of stresses and stress concentration is essential for the design of composite plates in field applications. The present work is focused on determining the stress concentration around countersunk hole in composite plate subjected to static in plane loading using finite element method. The effect of countersunk depth, plate thickness, countersunk angle and plate width on stress concentration around countersunk hole is carried out using finite element analysis. The variation of stress concentration with respect to the said parameters is carried out for uniformly distributed load. The results of finite element analysis are interpreted and some conclusions are drawn.

Keywords: stress concentration factor, composite plate, countersunk hole, finite element analysis.

1. INTRODUCTION

The usage of composites is increasing in aerospace and other engineering industrial applications, because of their high strength to weight ratios, high stiffness, low density and long fatigue life. As the application of composites to commercial product has increased, so has the need for design aspects for structural components. Accurate knowledge of deflections, stresses and stress concentration factors are required for design of plates with singularities such as circular hole. Any abrupt change in geometry of plate under loading gives rise to stress concentration; as a result, stress distribution is not uniform throughout the cross section. Extensive studies have been performed by Pilkey (Pilkey & Pilkey) on the stress concentration of two dimensional plates with hole and notches under different loading conditions. M. H. Dirikolu (2000) presented a comparative study of the stress intensity factor (SIF) for non standard thin composite plates by analytical and FEM. The work is specific to Carbon-Epoxy composite plate and concluded that the SIF decreases with increase of radius of the hole in the plate. Hwai-Chung Wu (2003) presented work on the analysis of stress concentration for isotropic/orthotropic plates and cylinders with circular holes. An empirical method for estimation of the stress concentration around hole is proposed. Lotfi Toubal (2005) investigated the tensile strain field of a composite plate around a circular hole. A non-contact measurement method, namely electronic speckle pattern interferometer (ESPI), is used for estimation of stress concentration around circular hole. The experimental procedure claimed is validated with analytical model and finite element methods. M. Yasar Kaltakci (2006) analyzed the fibre reinforced, symmetrically laminated composite plates containing circular holes for different fibre orientation in each layer. It is observed that the maximum stress value and its location around the hole is the function of the fibre orientation. Kambiz Bakhshandeh (2008) investigated the stress concentration factor for finite width orthotropic plate with circular hole using three dimensional finite element method. The effete of the opening radius to width of the plate ratio for different orthotropic plates with different orthotropy ratio is worked and concluded that with increasing the r/w ratio has less effect on SCF. Dharmendra Sharma (2011) presented work on stress concentration around circular/elliptical/triangular cut-outs in infinite composite plate subjected to biaxial loading for the effect of fiber orientation, stacking sequence loading factor loading angle and cut-out geometry. Moon Banerjee (2013) presented analysis of isotropic and orthotropic plate with center circular hole under transverse loading condition. The effect of thickness to width ratio and diameter to width ration on stress concentration factor is analyzed by finite element method. Feras Darwish (2013) investigated in plane stress concentration factor in countersunk rivet holes in orthotropic laminated plates under uniaxial tension loads using finite element analysis. The effect of plate thickness straight shank radius countersunk angle, countersunk depth, plate width and laminate ply angle on SCF is investigate. Praveen Saini and Tarun Agrawal (2014) worked on stress concentration around countersunk hole in isotropic plate under transverse loading. Three dimensional finite element analyses is done for countersunk hole in plate under different types of loading such as uniformly distributed load, uniformly varying loads and functionally varying load. It is concluded that the maximum stress concentration occurs at a particular point. The variation in the stress concentration distribution follows a similar trend for all three types of loadings. Nithis Prabhu (2014) investigated the stress concentration factor in carbon/e-glass fiber hybrid composite with a circular hole by experimentation for different orientations of 0°, 45°and 90°. It is found that when the fibers are loaded unidirectional and composite lie at an angle to the stress axis the effective strength of the composite is reduced. It is found that majority of the researcher have worked on stress concentration on isotropic plates with straight holes and very less work is reported on countersunk holes and there is a need for the stress analysis around countersunk hole in composite plate. This work is carried out to analyze the stress concentration around countersunk hole in composite plate under different types of loading such as uniformly distributed load. The effect of different parameters such as countersunk angle, countersunk depth to thickness ratio is studies by using finite element analysis software ANSYS.

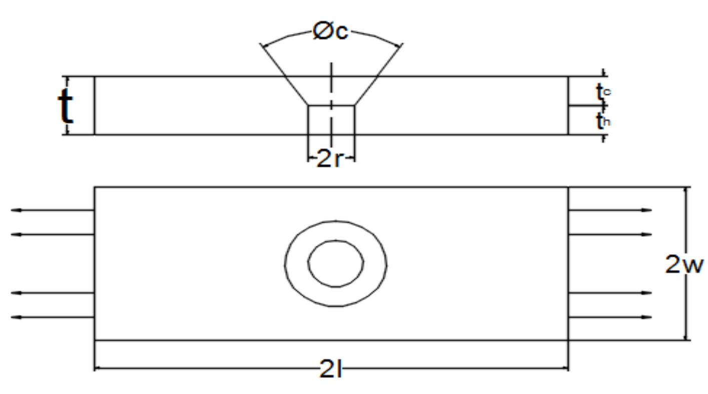

Figure 1 Configuration of countersunk hole

2. PROBLEM DESCRIPTION

The problem under consideration is a plate with countersunk hole and the geometric features of the same are shown in Fig. 1. The plate width is *2w*, length *2l* and thickness *t*, countersinking thickness C_s, and stress shank thickness *b,* shank radius *r* and the countersink angle θ_c. The countersink angle is taken in the range of $80^\circ - 120^\circ$.

The theoretical stress concentration factor (SCF) for normal stress is defined as,

$$K_t = \frac{\sigma max}{\sigma nom}$$

where the stress σ_{max} represents the maximum stress under actual load and σ_{nom} is the normal stress. For a rectangular plate with hole the under the action of the unidirectional force applied the σ_{nom} is calculated on the net cross sectional area as,

$$\sigma_{nom} = \frac{F}{(2w-d)t}$$

3. FINITE ELEMENT ANALYSIS

3.1. Model Preparation

The finite element model is created for finite plate with following dimensions, Half Length = 1000 mm, half width = 100 mm and thickness 10 mm. The opening radius to half width of plate ratio r/w is changed from 0.1 to 0.8. The properties of the composite plate are:

E_{11}= 44.7 GPa, $E_{22} = E_{33}$ = 17.9 GPa, $G_{12} = G_{13}$ = 8.96 GPa, G_{23} = 3.45 GPa, $\nu_{12} = \nu_{12}$ = 0.25, ν_{12} = 0.34., $\varphi = 0^\circ$

3.2. Meshing

The analysis is carried out by using finite element commercial code ANSYS. The model was meshed using a 3-D solid element, Solid 186 with three degrees of freedom and 20 nodes per element in ANSYS. Typical mesh of the plate using the above element is shown in Figure. 2. Mapped meshing is used so that more elements employed near the hole boundary. Due to the symmetric nature of different models investigated, it was necessary to discretize the quadrant plate for finite element analysis.

3.3. Model Validation

For the validation of the model the results obtained are compared with the Kt theoretical and it is found that the % error is well within acceptable limits. The results obtained by finite element analysis for straight hole in composite plate are compared with the results obtained by analytical method by Kambiz Bakhshandeh (2008) for composite. The validation of the FEA results with analytical results is shown in Fig. 3

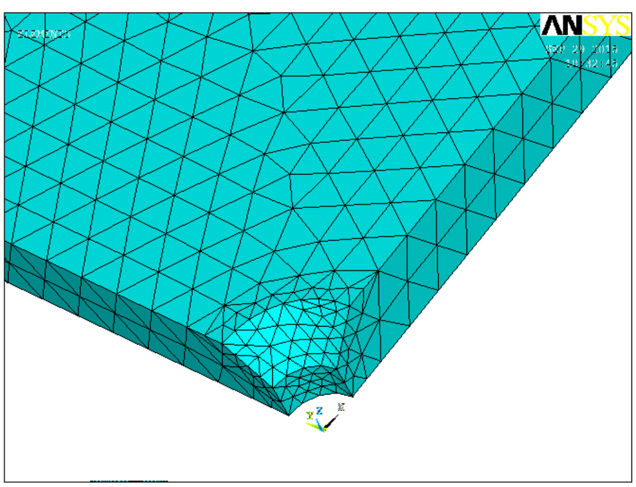

Figure 2 Quarter symmetric FE Model

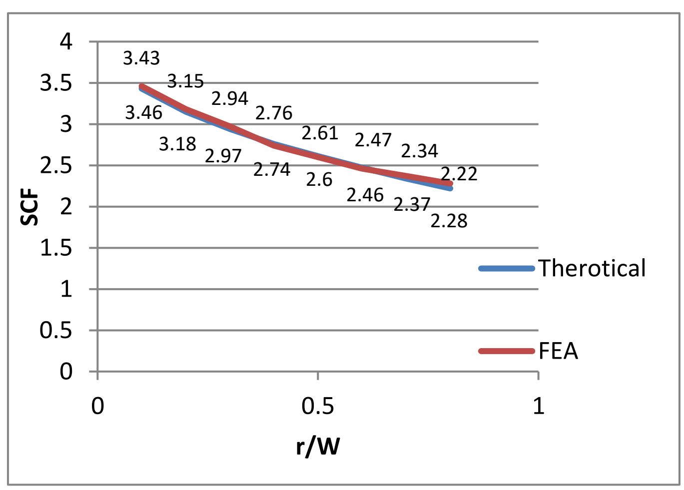

Figure 3 Comparison of SCF by Theoretical and FEA

4. RESULTS AND DISCUSSIONS

The results of the three dimensional analysis carried out for different parameters of countersunk hole

4.1. Effect of Countersunk Depth to Thickness Ratio (C_s/t)

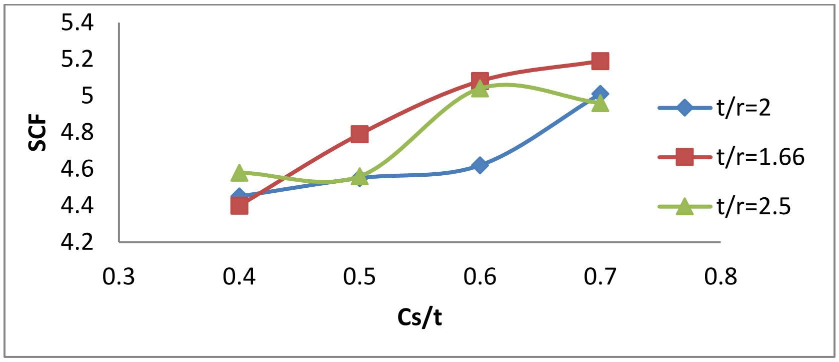

Figure 4 Effect of Cs/t on SCF.

The effect of countersunk depth (0.4, 0.5, 0.6, 0.7) on stress concentration factor for different t/r (1.66, 2, 2.5) ratios is as shown in the Fig. 4. The SCF is increasing with cs/t ratio but for the t/r ratio the pattern of variation is not same. SCF is in minimum at 0.5 for both 2 and 2.5.

4.2. Effect of Countersunk Angle (θ_c)

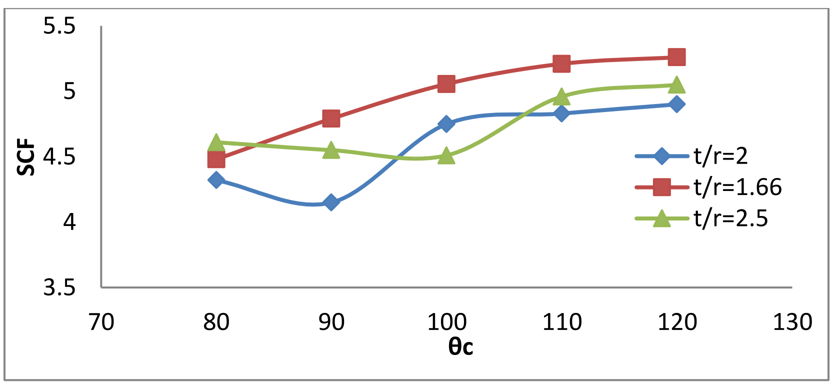

Figure 5 Effect of countersunk angle θc on SCF

The effect of countersunk angle θc on SCF is shown for different t/r (1.66, 2, 2.5) ratios is as shown in the Fig. 5. The effect is similar as the effect of Cs/t.

4.3. Effect of Thickness to Radius Ratio (t/r)

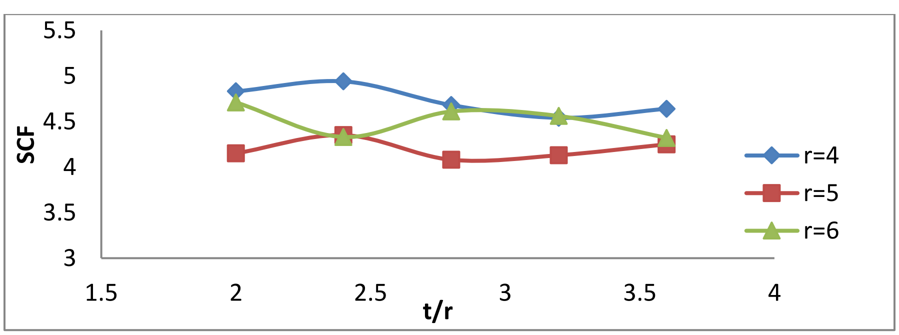

Figure 6 Effect of t/r on SCF

The effect of thickness to radius ratio on the stress concentration factor is shown in Fig. 6. the SCF is minimum between 2.5 to 3.5 for t/r.

4.4. Effect of width to Radius Ratio (w/r)

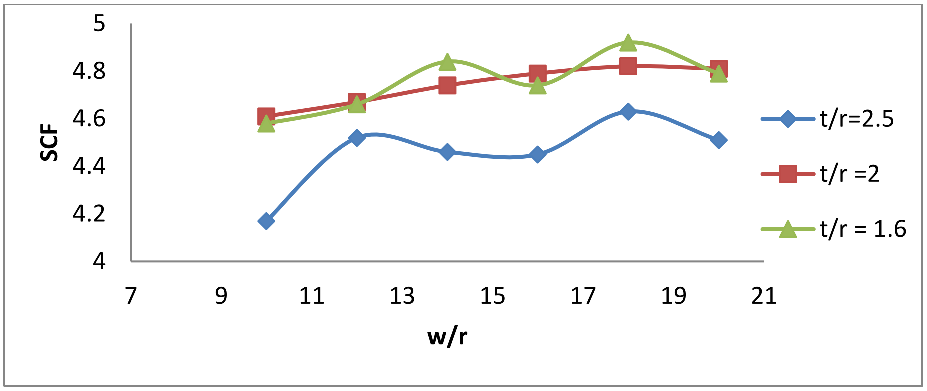

Figure 7 Effect of w/r on SCF

The effect of w/r on SCF for different t/r is shown in Fig. 7. The SCF is increasing for w/r ratio but is minimum between 15 to 17 for w/r.

5. CONCLUSION

A detailed investigation on the stress field and the stress concentration factor is done for countersunk hole in composite plate subjected to UDL by using three dimensional finite element analysis. A finite element code in APDL is used for modelling and analysis of the problem. A 20 node solid element SOLID 186 is used for the analysis. The finite element analysis has been conducted for a wide range of parameters as, countersunk depth to thickness ratio (C_s/t), countersunk angle (θ_c), thickness to radius ratio (t/r), and width to radius ratio (w/r) to evaluate their effect on stress concentration factor. From the FEA results it is seen that the maximum stress occurs at the edge of the hole. Also it can be stated that the results obtained are in line with similar works.

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